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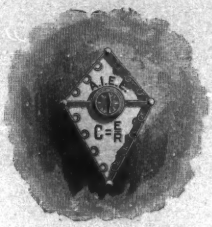

CONTENTS.

	PAGE.
Associate Members Elected April 22d, 1896	85
" " Transferred April 22d, 1896	86
Recent Developments in Vacuum Tube Lighting. (Illustrated.)	
By D. McFarlan Moore, April 22d, 1896	87
Discussion May 20th, 1896	110
Advertisements	127

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 22nd, 1896.

The 105th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.15 P. M.

The following associate members were elected by Council at the meeting in the afternoon.

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BALDWIN, BERT L.	Mechanical and Electrical Engineer, The Cincinnati Street R'way Co., 72 Perin Building, Cincinnati, O.	Nelson W. Perry. L. G. Lilley. John A. Cabot.
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MCCLUER, CHAS. P.	District Inspector, So. Bell Tel. and Tel. Co., Richmond, Va.	M. B. Leonard. Geo. A. Tower. C. E. McCluer.

SPEED, BUCKNER	Asst. Electrical Engineer, Louisville Electric Light Co., 1531 4th St., Louisville, Ky.	G. Wilbur Hubley. L. B. Stillwell. Alex. J. Wurts.
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Approved by Board of Examiners, Feb. 19th, 1896.

ANDREWS, W. S.	Electrical Engineer, etc., General Electric Co., Schenectady, N. Y.

Approved by Board of Examiners, March 20th, 1896.

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The following paper was then read by Mr. D. McFarlan Moore, and was illustrated with lantern slides. The hall was illuminated by the vacuum tubes described in the paper. Various experiments were also shown.

A paper presented at the 105th Meeting of the American Institute of Electrical Engineers, New York, April, 22d 1896. President Duncan in the Chair.

RECENT DEVELOPMENTS IN VACUUM TUBE LIGHTING.

BY D. MC FARLAN MOORE.

Most people have been accustomed to oil lamps, gas jets and other forms of light which have about reached their perfection. With the appearance of the arc and incandescent lamps it was thought that electricity had reached its limit in giving to the world a system of illumination that would leave nothing more to be desired. Indeed, it seems almost a presumption to dare to think of light being produced that would approach daylight in form and quality. The time is not so very remote when any man, who would have attempted to manufacture sunshine, would have shared the fate of a Galileo.

But fortunately the investigator of to-day has nothing of this kind to fear. Much arduous labor has already been expended in the solution of the problem by many eminent electrical scientists engaged in the study of vacuum tube phenomena, but the results from a practical point of view have been very meagre. This is chiefly owing to the complicated and expensive apparatus necessary, and the very unsatisfactory results even then obtainable. In fact, light from vacuum tubes, which is the only form of illumination that actually approaches nature's standard—daylight; has never been obtained in any quantity that would, in any way, be suitable for practical use. Of the other forms of electric lighting, the incandescent lamp is the most prominent. It is the peer of all illuminants in commercial use to-day, but is lacking, when we consider maximum uniformity in the distribution of light, and when calculations show that only three-tenths of one per cent. of the energy of the coal necessary to produce light by

incandescence (its name defines its character) is actually transformed into light, it is evident that there is room for improvement. The new electric light should possess all the good qualities of the present lamp with none of its drawbacks, and among its improvements will be noted the combination of utility and decoration. The recognized tendency of the day is towards multiplication of lights and avoidance of strong shadows—in other words, an even illumination, that is; light from all directions.

The object of this paper is not only to call attention to the advantages that will accrue with the adoption of vacuum tube lighting, but more particularly to a simple method of obtaining a current which will ultimately make such an adoption universally feasible. Almost without exception, experimenters in vacuum tube lighting have hitherto sought for the solution of the problem by merely pushing to the extreme, well-established methods based on principles long known in the art. That is, strictly speaking, no radical departures from the well-beaten paths have

FIG. 1.

FIG. 2.

been as yet brought forward. However, this paper does represent radical departures: in principles, in apparatus and in the nature of the current, resulting in a light of greatly increased intensity.

Before entering upon a description of the new system, permit me to call your attention to the methods heretofore used for obtaining light from hermetically sealed glass tubes containing a rarefied gas.

For many years the Geissler tube has been a scientific toy. When a suitable electric current is connected to its terminals, its entire length is filled with a faint glow. This is, of course, a light of radically different character from that now used in any commercial form of illumination. (See Fig. 1.)

It is light emanating from rarefied air with an apparent absence of heat and combustion. Upon this principle developed, probably depends the light of the future, which will soon be, in the opinion of the writer, the "light of the present." As a device for transforming electrical energy into light, the vacuum

tube is very efficient. The majority of authorities place it at about 70 per cent. and the incandescent lamp at two per cent. Notwithstanding this remarkable efficiency, it has never been commercially possible to illuminate by vacuum tubes, because the light could not be made sufficiently intense (this is expressing it mildly) even with bulky apparatus that was entirely impracticable.

Furthermore, the current produced by such apparatus was of such a nature as to render its insulation extremely difficult. The ordinary induction coil is often used for this purpose. A current of low voltage, such as that from a battery of a few cells must be used with such a coil, because a current of higher voltage could not be properly disrupted, the arc forming, preventing a sudden break of the current. But since the light depends on the suddenness of the break, the arc must be prevented, therefore the quicker the break, the brighter the light—provided the apparatus is properly designed.

The quickest break can be made by interposing in a circuit the most perfect dielectric in the minimum space of time. The best dielectric known is a vacuum, and I have discovered methods for interposing it in rapid succession in a current in a minimum space of time, depending upon the principle of making and breaking a current rapidly in a vacuum.

The disruption of any current in the air results in the formation of a spark of greater or less length, and the greater its length, the less sudden the break. Therefore, if the break be made in a vacuum, the narrowest conceivable complete gap in the metallic conductor results in an almost instantaneous discontinuance of current, ensuring a maximum C. E. M. F. The current is thus interrupted in an almost infinitely short space of time as compared with all the ingenious mechanical contrivances, such as air-blasts and magnetic blow-outs devised for the purpose of breaking a current suddenly in the open air, but all of which are of little avail for the production of any quantity of light.

The vacuum vibrator, as shown in Fig. 2, is the nucleus of my invention. Although an exceedingly small device (not as large as one's finger) it demonstrates when in circuit with a small magnet (not as large as a tea cup), a principle embodying great possibilities. It is a new piece of apparatus, exemplifying a principle of value not only applicable in practical use, but also an improved implement for scientific investigation.

It is almost unnecessary to describe such a simple piece of apparatus, which consists merely of a spring rigidly supported at one end, and having attached to its free end a small disk of soft iron. A contact point rests against the spring at about its centre. A sealed glass tube, from which the air is exhausted, encloses both spring and contact point. The system, as a whole, is exceedingly simple. An electric current passes through a coil of wire and then through the vacuum vibrator. Wires in contact with the outside of each of the ends of a closed and empty glass tube are attached to the two ends of the coil of wire. This statement embodies the gist of the invention. (Fig. 3.) It will be noticed that this system is far simpler than the apparatus ordinarily used to excite Geissler tubes. The secondary coil is absent, reducing the expense and bulk many fold, as are also the metallic terminals sealed into the ends of the Geissler tube, but it produces light, the desideratum, in wonderfully increased volume.

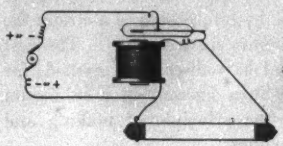

FIG. 3.

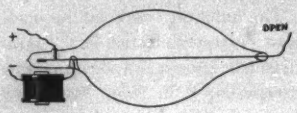

FIG. 4.

With this apparatus, currents of almost any voltage can be rapidly and suddenly interrupted, and it is therefore now possible to obtain, by using ordinary commercial currents, strong light in vacuum tubes.

When the circuit through the magnet and vibrator is closed, the armature within the vacuum vibrates rapidly, disrupting the current within the vacuum at each vibration.

The resulting high-tension current excites a brilliant luminosity in another tube, usually of much larger dimensions, and containing a lower vacuum than the vibrator tube. There is, therefore, a necessity for two vacuums, one the very highest, the other very low. However, I have tried a number of experiments, using but one vacuum, practically amounting to an enlargement of the vibrator tube and a lowering of its vacuum. (See Fig. 4.)

This is manifestly not a good plan for the production of light, because the breaking of the current does not occur in a high vacuum, but it led to an interesting line of experiments, the most novel of which will now be brought to your attention.

Within this low vacuum is placed a wire which can be bent and shaped into any form desired, as shown in Fig. 5. When connected to the vibrator, the beautiful effect is immediately apparent, the wire being enveloped in a delicate purple glow. This can be applied to various purposes, such as advertising. One

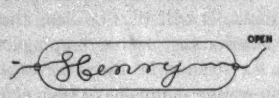

FIG. 5.

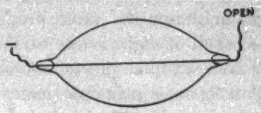

FIG. 6.

wire only, connects this sign tube to the vibrator, and it is attached to the armature terminal of the vibrator, because when so connected, it is the one which receives the high potential discharge of the magnet. In the bulb now shown (Fig. 6), the vacuum is higher, and a single wire extends through the centre. The light, instead of appearing as a purple envelope around the wire, now fills the entire chamber with a beautiful milky glow.

Close inspection, however, reveals the fact that there is a very small dark space immediately encircling the wire, and beyond it there appear to be rapidly moving rings of light, concentric with it. In fact, one is reminded of the field of force surrounding a conductor, as displayed by the familiar arrangement of iron filings—indeed, it is a similar phenomenon—the molecules of the residual gas taking the place of the iron filings.

The next bulb (Fig. 7) is similar to the one last shown, but with one exception. The wire is not single throughout its entire length; for a space of about three inches at its centre it separates into six strands, which thereby form a kind of cylindrical cage

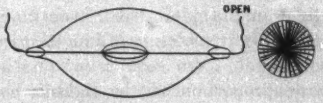

FIG. 7.

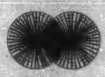

FIG. 8.

about one-half inch in diameter. In this case the entire bulb is not filled with a glow, but the interior of the cylinder forms a pencil of light quite dense, denoting that a new principle is brought into play. It is this—every current creates its own electrostatic field around its conductor, which, when immersed in a gas

at the proper degree of rarefaction, causes it to give forth light, which is most dense in a comparatively small circle surrounding the conductor. (See Fig. 8.)

When two wires, each having its field of force, are placed parallel to each other and about one-half inch apart, the density of the field between them will be doubled, and consequently the light in almost the same proportion. It will thus be clear that the pencil of light is due to the intersecting or overlapping of the fields of force of each of the six strands forming the cage. Upon this new principle many interesting lamps have been constructed, the problem being to get a maximum number of fields of force to intersect. Probably the best solution is in a cylinder made by spirally winding a wire, as in Fig. 9, causing its field to intersect in a manner that is almost ideal. This explanation may seem at variance with Faraday's famous experiment, proving that an electrostatic charge does not reside in the interior of the charged body. The vacuum may make the difference.

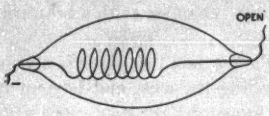

FIG. 9.

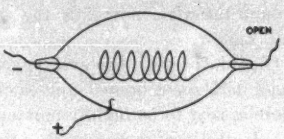

FIG. 10.

In this bulb (Fig. 10) there are two separate terminals projecting from the glass. When the spiral is connected to the negative pole of the vibrator, and the other terminal is made positive, the light is greatly increased. Such a lamp can be very conveniently made by using an incandescent lamp bulb, as in Fig. 11. The bit of platinum wire extending into the bulb and forming the positive pole, can be placed in any of the positions 1, 2, 3, 4, 5, without affecting the light in the spiral, but it is apt to become heated, and this is remedied by attaching to it a metal wire ring. (See Fig. 12.)

In these lamps a large proportion of the light is confined within the spiral, and since volume is desirable, the idea of increasing the number of spirals suggests itself, as in Fig. 13. But the total volume of light emitted by four spirals is only equal to that of a single spiral lamp, that is, each pencil is but one-fourth as bright; hence, to bring them all to full brightness, the energy of the inductive current should be increased in proportion.

With the idea of obtaining from the entire bulb a uniform glow, the lamp shown in Fig. 14 was constructed. The "filament" consists of a great many complete loops of very fine aluminium wire. Fine wire was used, not only because of appearance and weight, but also for two other reasons: 1st, because a fine wire has about as large a field of force as a much larger wire; and, 2nd, because it does not obstruct the light so much, and at the same time is a minimum of metal within the vacuum. This is a matter of much importance, as upon it largely depends the life of the lamp. A great many different conductors were used for the construction of these filaments, the main idea being to use that material which contained the least occluded gas, and would be disintegrated a minimum by the action of the current. Fig. 15 shows ordinary incandescent lamp filaments utilized in a glow lamp, but one leg only is cemented at the centre of the bulb to

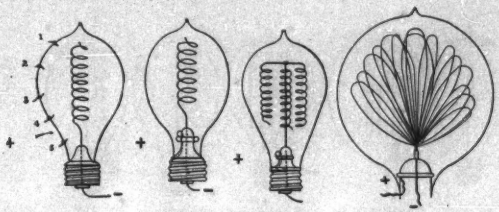

FIG. 11. FIG. 12. FIG. 13. FIG. 14.

the negative terminal, the other being free—a veritable fountain of filaments. A rather curious and not entirely explained phenomenon was noticed in this form of lamp, *viz.*, the free ends of the filaments were apt to be violently agitated, and whenever they touched the glass of the bulb, they heated up to a bright red throughout their entire length, producing a most brilliant combination glow and incandescent light. Many are the advantages of these lamps over those using fluorescent materials, as the sulphide of zinc or calcium. Sometimes when the exhaustion is carried a little too far, the vibrator current is unable to affect the lamps, but after they are held in contact with one pole of a large induction coil for a few moments, and then connected to the vibrator current, the trouble ceases.

In all of these forms of lamps it is very interesting to note that in order to get maximum light, the sub-divided terminal of the

lamp must be so connected to the mains that it is negative. This is interesting to remember when the subject of lighting tubes is considered.

The class of lamps will now be considered where, instead of sub-dividing the lighting electrode into filaments, plane surfaces are used.

The bulb in Fig. 16 contains two pieces of sheet aluminium equal in size, set with their planes at right angles to each other, in order that a minimum of light may be interrupted from any point of view, and that the positive will act as a reflector to the negative. These pieces of aluminium must be carefully cleaned before being placed in the lamp, because any grease upon them will cause beautiful tufts of light all over their surfaces, instead of a glow filling the bulb, and the vacuum will soon be lost. Of course, in a lamp of this construction the poles can be changed

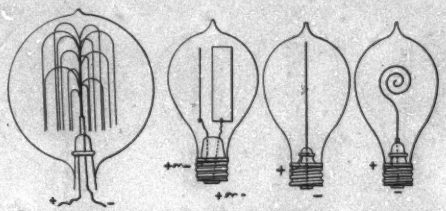

Fig. 15. Fig. 16. Fig. 17. Fig. 18.

with impunity, and if an alternating current be passed through the vibrator, both plates will give light, but the total amount will be the same as when direct current is used.

One of the many modifications of this form of lamp was to make the magnetic pole in the form of a small cylinder of aluminium gauze.

Many lamps were made on the principle of a spiral within a spiral, wound in the same or opposite directions, and also of using metallic coatings on the tubes interior and exterior, as well as using bulbs of all shapes and sizes. One important advantage to be noticed in all these forms of lamps is the total absence of the very objectionable striations, such as occur in the ordinary Geissler tube.

Fig. 17 is a very simple form of lamp—merely a single piece of straight carbon filament producing the light.

Fig. 18 is another of peculiar form—an unusual density of white light inside the convolutions of the spiral.

To determine whether there was any appreciable heat at the centre of an intense pencil of light, a number of lamps were constructed in which various substances were placed at the point of greatest density of light, as in Fig. 19, but in no instance was the substance affected in any degree whatever.

Following out this idea a little further, there was inserted a small glass tube containing air properly rarefied in the centre of a spiral, as in Fig. 20.

But the inside of the small tube remained dark; nevertheless, the glow outside of the spiral, dark space and other phenomena, even to the tufts of light between some of the convolutions of the spiral are the same as those in a similar lamp without a tube, inside its spiral.

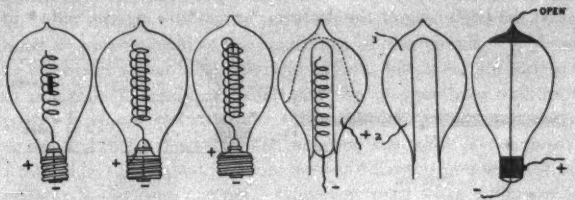

Fig. 19. Fig. 20. Fig. 21. Fig. 22. Fig. 23. Fig. 24.

Another lamp was then made the same as the last, except the tube inside the spiral has a platinum wire extending into it, which wire is electrically connected with the spiral (Fig. 21.) Of course, the small tube was tried separately before being placed in the lamp bulb, and it filled with a white glow. But after the lamp was completed it refused to give any light; the glow outside the spiral, however, was the same as though there was no inner tube present.

Hoping to get a lamp with almost no metal in the light-producing vacuum, the lamp shown in Fig. 22 was constructed—the spiral is within a separate tube. When tried, a tuft of light appeared in the top and bottom of the small tube which was surrounded by a faint glow, the outlines of which are shown by the dotted line.

The next step was to do away with the inner vacuum and con-

struct a bulb as shown in Fig. 23. When a spiral was inserted in the tube and connected to the negative pole, the positive being either 1 or 2, a dark space one-eighth inch deep surrounds the tube, beyond which a faint pinkish glow appeared filling the bulb. The phenomena known as "afterglow," which is sometimes noticed in evacuated bulbs after having been subjected to an electrostatic strain, I have been able to obtain, but very seldom. (Fig. 24.) However, this bulb could be picked up and carried around the room, but every time it was picked up after being laid down, a discharge resulted, which, being repeated three or four times, dissipated the glow entirely.

From a tube containing two parallel wires, shown in Fig. 25, but with a low degree of exhaustion, the glow was entirely absent, but instead, brilliant, flaming yellow discharges completely filled the space between the wires, which was over half an inch wide and about two feet long.

At the beginning of the lecture your attention was called to

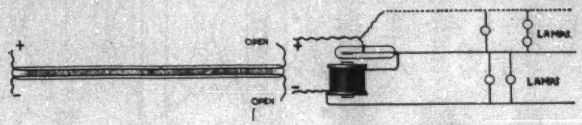

FIG. 25. FIG. 26.

the great similarity existing between the field of force of a "cold-light" giving conductor in a partial vacuum, and that of a conductor conveying a current in the open air. Care, however, should be taken to note that the light from the rarefied atmosphere is due to electrostatic and not electromagnetic phenomena.

For example, I have here a powerful electro-magnet which I connect directly across the lighting mains, and therefore, it is one at whose centre or core the electro-magnetic field is very dense. When this tube, which has a diameter the same as that of the core of the magnet, has about half of its length passed through the centre of the magnet, no light whatever results. If, however, but one terminal (the other being free) of this same magnet be connected to the vibrator, immediately the tube gives forth light.

Referring again to the subject of connections, Fig. 26 shows the light connected around the terminals of the magnet; it also can be connected with equal results around the break or spark

gap as shown by the dotted lines. Your attention is called to the fact that lamps of this kind will operate equally well, whether connected in multiple or in series, provided the area of the negative electrode is about the same in each; if not, that one in which the negative electrode is of greatest area will alone light up.

If a single bulb of small size be connected to a circuit of considerable induction, a well-defined discharge is liable to occur which will ruin the lamp.

In Fig. 27 an inductive resistance is distributed with each lamp, making the system of distribution self-regulating, that is, the turning on or off of lamps will not affect the brilliancy of those burning steadily.

Referring again to the diagram of circuits showing the system in its simplest form: If good results are to be obtained, the magnet must be designed and constructed with the greatest care. Its duties are two-fold; first, to give the vibrator its mechanical motion, and second, to act as an inductive resistance. The iron core must be proportioned to the conditions of the circuit. If there be too much or too little, the light suffers, but a certain amount of iron should remain, in order that the magnet have sufficient power to vibrate the armature. Similarly if there be too many or too few turns of wire on the magnet, the light is decreased. From this it is evident that vibrators of different rates will not be suitable to the same magnet. However, even when a vibrator is connected to a suitable magnet and circuit, and produces a good light, it can be further improved by "tuning the circuit," that is, altering its self-induction by varying the amount of iron in the magnet's core. It should also be stated that by this means a maximum light is obtained from a minimum current. In order that the time constant of the magnet be a minimum, and to ensure rapid action, the magnets should be short and thick. Large induction coils cause the tubes or lamps to give forth but little light, whlle a small magnet, whose length of wire is not $\frac{1}{100}$ that of the induction coil, will cause the tubes and lamps to light up brilliantly.

It is interesting to note that with a comparatively few turns of wire, a very small one-volt battery will give quite a strong glow. This glow can be intensified by using a secondary coil.

Although the various lamps that have been described are of great interest, nevertheless the very nature of lighting by luminescent gas is such, that it is far more applicable to radiate from

sources of considerable area than from units of light of small area. The best method of obtaining light from a large area is by the utilization of tubes of considerable length, instead of small bulbs. The light of these tubes should be entirely free from the very objectionable striations always present when interior electrodes are used; but these striations are entirely obviated by using exterior electrodes. They may be metal caps on the outside of the tube, or preferably merely coatings of metallic paint. Such tubes can be made up in almost any lengths, and can be bent into a great variety of forms, making them suitable for exquisite decorative effects. Under this head can be mentioned the fashioning of tubes in the form of letters, which may be used as electric signs.

Permit me to call your attention once more to the key of the whole system, viz.:—repeated interruptions of an electric current in a high vacuum.

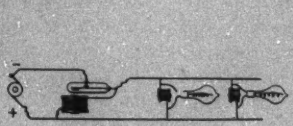

FIG. 27.

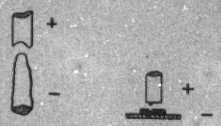

FIG. 28.—Electric Light Carbon. Vibrator Contact Points.

The simplest method of accomplishing this object is to hermetically seal within a glass tube a vibrator of ordinary form, but its exact construction to give the best results has been a matter of tedious experimentation and study. The very slightest alteration in the dimensions of almost any of its parts—such as the length, width and thickness of the spring, or its method of mounting, or the position of the contact points, or the thickness or diameter of the armature, will cause it to be a very good, or a very poor vibrator. Again, the operations of the glass-blower had to be watched most carefully. Only certain kinds of iron and steel were selected, to avoid occluded gases, and even then they must undergo a special treatment before being fit for use. The selection of suitable contact points has also been a large field for research. Nearly all known conductors have been tried, and many interesting facts have developed in this connection, not only so far as the direct action on the various metals in vacua and various gases is concerned, (and this several in instances is

the reverse of the phenomena noted in open air), but also with reference to the electro deposition or electrolytic action that takes place. For instance, as is well known, the positive electrode is the one which disintegrates most rapidly in the open air, and its apex is usually concave. This is probably best shown in the ordinary direct current arc lamps. If aluminium or any soft metal of comparatively low fusing point be used as contacts in a vibrator, after about a day's run, an examination shows that the shape and condition of the contacts is just the reverse of the way they appear after use in the open air. That is, the positive terminal looks like the negative, and the negative like the positive. (See Fig. 28.)

I have constructed several dozen distinct varieties or amplifications of the ordinary type of vibrator, such as multiple contacts, etc.

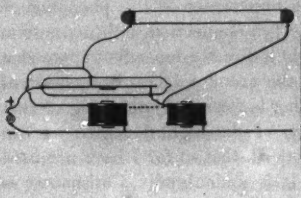

FIG. 29.

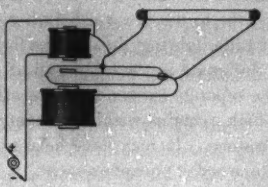

FIG. 30.

Fig. 29 shows one form, in which the object was to produce a larger number of breaks of the current per unit of time by providing two contacts, as shown. In some respects this scheme worked well, that is, the light was stronger than that produced by an ordinary vibrator with a single magnet, but the light was not steady, and when the connections were changed so that but one magnet was used, the light flickered still more. All the vibrators, so far considered, have had their springs so adjusted, that the contacts remained normally closed. Fig. 30 shows a circuit using a vibrator normally open. The small magnet constantly closes the circuit, and the large one opens it. This arrangement gave a good light. A number of ordinary vibrators have been operated, arranged with the magnet above the armature, so that gravity helps close the circuit. Of course, springs and armatures of scores of shapes and sizes, including gravity vibrators, have been tried, the principal object being to obtain a method

for taking up the wear of the contact points; but the best solution of this problem lay in getting contact points that would not wear because of a more perfect vacuum.

Turning now from the mechanical construction of vacuum vibrators to consideration of their unique properties from a scientific standpoint. As stated before, roughly speaking, the prime object of making the break of the current in a vacuum is to produce an increased C. E. M. F. over that resulting from an air-break. But I venture to say, few as yet realize the possibilities and the tremendous advantages involved in the separation of electrodes in high vacua at regular periods of time. It is indeed questionable whether the increased C. E. M. F. of the ether gap is responsible for the results. It is more probably due to the fact that the wave lengths of the current resulting from an ether gap differ radically from any that have heretofore been known of. Recognition of the importance of this phenomenon led me to use the word "etheric" in connection with my system of tube lighting, because the light is directly dependent upon what I designate as the ether gap of the vacuum. Our best notion of the separate existence of the ether is formed by thinking of that which remains within a vacuum of the highest degree we can produce. It may have been noticed, that so far I have not used the word "phosphorescent." It is undoubtedly a misnomer as applied to tube lighting; but to make matters worse, there seems to be no word in existence exactly or even approximately suitable.

The word etheric is especially applicable to light produced by the ether gap. That incomparably better results should be obtained by using a vacuum as a dielectric seems to be in perfect accord with accepted theory which has largely been upheld by actual experimentation. For example, setting aside for the time being that part taken by the maguet, let us consider only the break,—the spark.

First, what is required is a continuance of the rapid oscillations of an electric discharge, and I desire to show that this is accomplished by a vacuum vibrator in an ideal manner. One method of obtaining an oscillating discharge is to use a potential such that an air-gap of considerable width is bridged by the spark. But the manner in which such discharges succeed each other largely depends upon the irregular movement of the air within the gap.

This method is unsatisfactory for many other reasons, among them the very objectionable high tension required, but there remains the conductive method of causing a spark, exemplified in the ordinary vibrator and induction coil. Here the sparks in the primary circuit can be made to succeed each other quite rapidly, but the length of time required for each complete break is long. However, with the vacuum vibrator, a new and simple device, the conditions are different, and so are the results. Here the dielectric is an exceedingly thin film of ether, which is capable of withstanding a great electrostatic strain, but when it does break down, it does so very suddenly; that is, it may be considered a *perfectly* disruptive discharge, and therefore its single oscillations are very short; but as a whole they are long continued. This means that the frequency is high, and, according to Maxwell, very high frequency oscillations are probably identical with light.

The small magnet, being a circuit of induction, has its own natural period. But its period and moment of inertia will be less, the less its capacity. That is, the smaller the magnet the smaller the period, or the higher its frequency can be.

But to have an intense light, there is required a high E.M.F. of self-induction. This the small magnet furnishes, because what is lost in self-induction by using a comparatively few turns of wire is more than made up by the suddenness of the discontinuance of current flow, and the fact that the high vacuum precludes the possibility of loss to the self-induction ordinarily due to the glow discharge which precedes the disruptive discharge in the air. The self-induction also depends on the *amount* of current flowing through a circuit when interrupted, and this the vibrator provides for, in that *all* the current which flows through the coil does not pass through an arc, but is transmitted over actual metal contacts. Also since these contacts are so very close, due to the thinness of the dielectric, the oscillatory discharges do not leave the metal and pass in objectionable minute streams through the vacuum. And the number of oscillations in the coil and the amount of light, depend in a measure on energy expended to overcome the resistance of the dielectric which is almost infinitely greater than that of air.

That the silent discharge prevents long continuance of oscillation is shown in the Hertz experiments, where the experiment fails unless the balls of the electrodes are kept polished. That

the vacuum vibrator is nearly ideal, is again shown in that these troubles are almost entirely eliminated. The ether is undoubtedly the ideal medium in which to disrupt an inductive circuit for conversion into light. Since an exceedingly thin film (if this term may be so used) is a dielectric of such strength that a very small displacement results when it is disrupted, and the ether being the medium of minimum rigidity closes the "hole" the instant it is pierced. Such a medium for such a purpose is almost incomparable to air or oil, which becomes volatilized.

In order to get any oscillations, more sudden rushes of current must occur on discharging than on charging, and the more nearly these equal each other, the quicker the rushes will succeed each other. Now, in the case in question, when the tube circuit with its condenser coatings has a certain capacity, the self-induction of the magnet can be so varied that these two will always neutralize each other, and then the critical strain on the dielectric requires but little energy to cause a discharge, and the circuit being almost balanced, the surges follow each other in rapid succession through the tube. The surges continne for a longer time, since the energy of the discharge is not dissipated in heat on the air, but is conserved to be utilized in prolonging the existence of the oscillations. The use of this vibrator seems to afford the best means yet invented for impressing molecular disturbances in a tube. The longer the oscillations exist, the more nearly the mean oscillation approaches a constant period, and this period is practically governable as compared with that of currents due to magnetic blasts or heated air currents. The higher the frequency, the greater the mean free paths of the molecules, because a less number of molecules will then be required to cause a given number of collisions, and the less the number of impacts, the greater will be the light in proportion to the heat. But the frequency is dependent on the capacity of the condenser, which, in the case of the tube coatings, is very small.

When the self-induction and capacity are properly proportioned, and the rate of the vibrator is the same as the natural period of the coil, *or any of its harmonics*, then there is resonance, and the maximum amplitude of each impulse will be constant. In this case the current flow is at its maximum, but so also is the voltage at the ends of the tube, as well as the quantity of light produced with a minimum expenditure of energy. The velocity of the lines of force produced by an oscillatory discharge is supposed

to be equal to that of light, but its wave lengths are exceedingly greater. But this disparity is greatly reduced by the vacuum vibrator. This accounts for the intense light in the tube at comparatively low potentials, and indicates that nature's keyboard has been struck to the tune of 500 trillions of waves per second, and that this rate is maintained by the fundamental mechanical vibrations of the vibrator—about 100 per second—a most beautiful demonstration of nature's wonderful compass. But not only is more light produced by the vacuum vibrator than was heretofore obtainable, but there accompanies it many other advantages of particular importance. Three of these can be mentioned:—first, simplicity and greatly reduced cost of apparatus; second, the obviation of impracticable potential, and third, a very marked advance in economical production. The first heading, simplicity, has already been dwelt upon. Compare an inexpensive magnet, not as large as one's hand, and a vibrator the size of one's finger, attached to commercial currents, with apparatus costing thousands of dollars, consisting of a high speed alternating dynamo of many coils, oil transformers, disruptive discharges with magnetic blast, induction coils and condensers. The many seemingly unsurmountable difficulties encountered with this method, are almost completely overcome by the simple expedient of the ether gap. Or, referring to ordinary induction coils, the vacuum break affords a means for obtaining from the few turns of comparatively coarse wire, results not obtainable with mammoth and expensive coils, made of many miles of wire, and capable of creating enormous differences of potential.

The second heading is essentially a practical one. It has often been argued, to the detriment of tube lighting, that since it was admitted by its supporters that enormously high potentials were absolutely requisite to cause any appreciable amount of light, that therefore (and the argument was logical) the whole idea was extremely impracticable unless some new insulator be discovered, that could cope with the high potentials, so difficult, dangerous and expensive of generation and manipulation, as to prohibit their use commercially. But with a current endowed with such properties as are given it by a vacuum tube vibrator, no new insulator is needed.

A light now results many times brighter than that formerly due to millions of volts, able to pierce several inches of hard rubber, or produce a spark many inches in length, from a current

transmitted to the bulb or tube over ordinary flexible cord, and whose sparking distance is less than $\frac{1}{16}$ of an inch. Neither can any shock be felt from such a current. Another example of the comparative ease with which this new current can be insulated is apparent in the magnets, wound in the ordinary manner, in striking contrast with the necessity for expensive and cumbersome oil transformers. In this light the exclusion of all gaseous matter does not seem to be a matter of such vital importance.

Closely allied with the subject of insulation is that of frequency. The higher the frequency, the lower the potential can be, not only with respect to light, but also to insulation, because irregularity in the rate of vibration puts the insulation to a severe test. However, the period of the vibrator is not rapid as compared to that of alternating dynamos, constructed to obtain similar lighting effects, but resulting in those of lesser degree. The alternations of such a machine are about 30,000 per second, which is further increased by a disruptive-discharge coil. This was necessary to compensate for the long wave lengths of the current. But since these lengths are so much shorter in the vacuum vibrator current, an initial frequency one-fifth as great, without the use of additional coils and condensers, produces far better results. But that an ordinarily constructed vibrator can attain a speed of 6,000 per minute, may be questioned, when it is remembered that induction coil vibrators work at a rate of but a little over 1,000. The difference lies in the fact, that the vacuum vibrator has no air pressure to impede its movements, and also that a much shorter space of time is required for a single complete interruption, because the actual mechanical movement can be much less, yet cause a complete break, and another cycle has begun. The speed of the vibrators is ascertained in two ways:—first, by comparing the musical note it produces with that of a pitch pipe, and secondly, by a visual arrangement constructed and operated as follows:

A shaft, supporting a wheel with one spoke, is rotated rapidly by hand, a series of multiplying gears being used, so that when the hand makes one revolution per second, the spoke makes twenty. When this apparatus is operated in a room, lighted only by a single vacuum tube, the spoke will appear stationary in one, two, or three positions, according to the rate of the vibrator. For example, if the spoke appears stationary in two positions, it indicates that it is illuminated twice in a single revolution, each image being due to a vibration.

Another subject, which has been a serious obstacle in former proposed systems, is that of impedance. The fact that the best conductors would cease to transmit current, seemed a difficulty almost unsurmountable; yet it appears to be almost absent under these new conditions. For example, when a large coil is inserted in the high potential lead from the armature terminal to the tube, the effect on the light is surprisingly small. The result is the same, whether the wire be in the form of a magnet, or in a long exposed line. But, nevertheless, on account of line losses, it is advantageous to prevent condenser action by using a wire as small as possible, yet able to stand the strain it is subjected to when its insulation is being placed upon it. Although the light produced by a single wire is quite good, it is decidedly advisable for best results to use a return wire, because the fundamental frequency is so low.

The third subject—economy—is so large, and of such importance that I deem it expedient to make it the subject of a future paper when accurate measurements have been made. Indeed, it is second only—but it is second—to the nucleus of the whole investigation, *viz*, getting light. The efficiency of the lighting tube is well established, due principally to the great amount of light accompanied by so little heat that it has by some been called "cold" light. The temperature of the gas within the tube varies with the density of the discharge from 12° to 132° C.; but even this is improved by the shorter wave lengths. These figures are extremely low, as compared with temperatures as high as 3,500° C., which must be reached by some substances in order that the light be white and the spectrum complete.

Owing to the peculiar characteristics of the current, the line losses are materially decreased, and the current flowing through the primary circuit is less when the tube is giving light, than when it is disconnected. There are almost no losses for motive power to disrupt the current, for the magnet is its own motor. But the greatest loss has always been in the disruptive discharge, —the spark. It is remarkable how easily several horse-power can be dissipated in the air through the intervention of a disruptive discharge. In this connection it should be borne in mind that magnetic blow-outs and air currents are merely heat dissipaters, and increase the loss, while these losses are entirely obviated by the vacuum vibrator. The current can perform a

large amount of work on the air, unlimited in volume, with no apparent results; but when this volume is reduced to the compass of a small vibrator tube which remains perfectly cool in operation, does not the question of efficiency assume a different aspect?

Upon these reasons may be based logical conclusions, pointing to an enormous increase in efficiency over that of all other methods of obtaining light in tubes.

The theory which has just been considered, of course, is not limited to a simple vibrator, but applies broadly to any method of interrupting the flow of current through a high vacuum. This can be accomplished in a great variety of ways, although as far as simplicity of apparatus is concerned, the regular spring vibrator, in connection with a single magnet, probably cannot be improved upon.

The first deviation, however, is to use a very small magnet to vibrate the armature, and to connect this in series with a larger one to furnish the induction. But in these cases the power of the operating magnet depends on the current passing over the contact points; hence to make the light which is dependent on the contact points perfectly positive, the power should not be dependent upon them, and separate circuits suggest themselves—that is, cause an intermittent current to flow through the power magnet that does not flow through the contact points of the vibrator, which have in circuit with them the inductive magnet. Or the electrodes can be separated by mechanical jarring instead of magnetic power acting through the glass.

If an ordinarily constructed vibrator be attached to any form of rapidly oscillating mechanism, the contacts within will be opened and closed rapidly. But in order that the light be steady, the movements of the vibrator armature must be in step with the movements of its mechanical support. This is best accomplished by having the centre of the oscillation of the vibrating armature coincident with that of its oscillating support.

It is plain that it is unnecessary that the current be interrupted by a reciprocal motion only; a rotary motion is also applicable.

Fig. 31 shows a form somewhat analogous in operation to the simplest vibrator, except that the rotary momentum of the armature takes the place of a spring, and the break-wheel which furnishes the light also acts as a commutator to the simple form of motor.

Another way of obtaining a rotary motion within a vacuum is to attach a pendant weight to a ratchet wheel, free to rotate upon a shaft attached to which is the brush. Since the shaft is rigidly sealed into the glass, it is evident that when the bulb be rotated by a motor, the brush will revolve around the break wheel. The fault with the device is that the pendulum will have a vibration of its own, causing the light to waver.

In order that the make-and-break devices dependent upon a rotary motion be absolutely positive, a rotating magnetic field has been utilized. Since the experimental side of these investigations has extended over but a few months, it is at present difficult to say upon which of these methods, developed, the system will take final form.

Returning once more to the subject of the light in the tube. It is interesting to note, that although the most intense light is

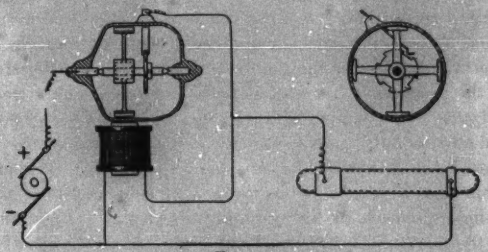

FIG. 31.

produced when both of the ends of the tube are connected to the electrodes, it is well known that light also results when the tube is merely placed near an electrode without actual contact. This phenomenon is known as lighting by induction.

If an inductive circuit, sufficiently powerful to brilliantly illuminate a tube four feet long, be transferred to one two feet long, there will appear at the center of this small tube a very intense thread of silvery white light, which undulates as if it were a material substance. It is interesting to contrast the color of the light of these tubes with that of an incandescent lamp. The reddish and wasteful glare of the latter, indicating heat waves, and the pure daylight white of the former, is immediately apparent. It is this difference in color that makes an efficiency calculation so difficult. It is very easy to ask the question :

How many watts per candle-power? But in most instances it indicates a lack of information on the part of the questioner. The question should be: How many watts per amount of light equivalent to one candle-power? But even this is not perfectly correct, because it is well nigh impossible to compare accurately lights of a different color and power of diffusion. When the *use* the light is to be put to is stated, the problem is much more simple. For instance, if it is to be used to read by, the range of legibility can be made the basis of comparison between the true glow lamp and the candle. This most popular form of illumination, from the 12th to the beginning of this century, is still the standard of illumination, although it is probable it will soon be deprived of this honor. I may be pardoned for calling your attention to the remarkable intensity of the light in these tubes, in connection with the statements repeatedly made by eminent scientists, that such intensity was an impossibility, and that efforts in this direction were comparable to those wasted on perpetual motion. It is merely another instance of history repeating itself, in that in all times the inertia of the learned has interfered more with the progress of science than has ignorance. Be it remembered that the commercial incandescent lamp was an acknowledged impossibility among scientific men, and that by them the proposed Atlantic cable was considered foolishness. If there be but one lesson taught by our times, it is, condemn nothing *new* in religion, science or art without thorough investigation, and even then be careful, because many suggestions, though of little value themselves, have led to great advancement. It is also well to remember that there is almost a creative force in the spirit that is earnest and courageous. The light having reached the intensity, as you see it in this tube, it is questionable whether much greater intensity is wanted. The vibrator, as applied to the electric bell, was the first practical application of electric power, and to-day we see the same vibrator in a "new light."

The very nature of the light, if it is to be counterpart of the ideal-daylight, is such that when a square inch of the surface of the tube emits as much light as that thrown into a room through an aperture one inch square, the want is satisfied. Then the desired illumination can be reached by multiplying the area and length of the tubes, and distributing them in the most advantageous manner, that is, so that the light will fall from all directions. When a considerable area is to be lighted, the most efficient light is the

one that is most equally distributed. However, there will always be a demand for units of light. Even this can be satisfied by using a tube of small calibre. This lamp is made by winding a small tube in the form of a spiral, its ends, to which the wires

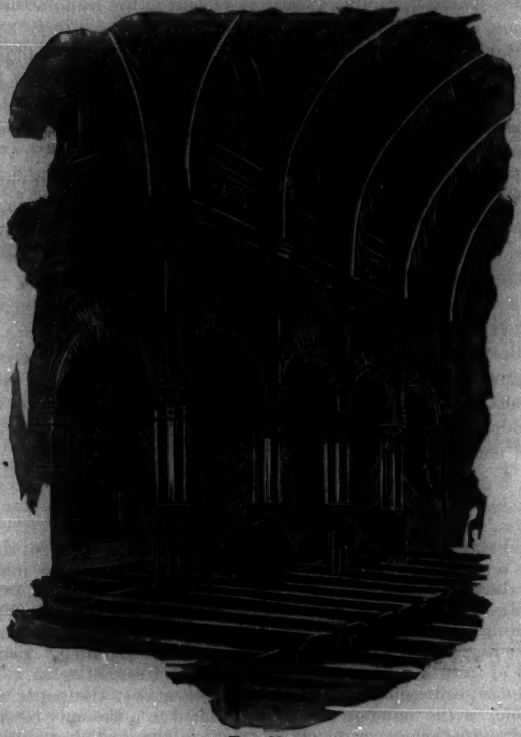

FIG. 83.

are attached, terminating in oblong bulbs three or four times the diameter of the small tube.

I have previously stated that the alphabet has been constructed of tubes of light. Here are the initials of the body I have the honor to address, A. I. E. E., in letters twelve inches high. The

delicate shades of these letters cannot fail to elicit admiration from all who love the beautiful.

The principle of breaking a circuit in a vacuum has many applications to a variety of uses. Among them may be mentioned, advertising signs, decorative electric lighting, electrotherapy, philosophical apparatus, theatrical effects, in the manufacture of ozone, in the kinetoscope, etc., etc.

But the greatest field will ultimately be that of general illumination. You have noticed the tubes extending around this hall. Undoubtedly this is the first time that lighting by tubes has been attempted on so large a scale. You will note the almost entire absence of shadows.

Fig. 32 illustrates what we are coming to in the way of church lighting. For some time past everything has pointed to the general adoption sooner or later of some such form of illumination, and since volumes of light can now be produced, and of commercial intensity, does it not indicate that already this light is a matter for serious practical consideration, and no longer a pyrotechnic curiosity?

But the only way in which one can form a comprehensive or appreciative idea of what advance in this line of work really means, is to compare the situation of to-day with that, not of a hundred years ago only, but with that of only twelve months ago, and note the contrast.

Discussion.

[Owing to lack of time at the meeting of April 22d, there was no opportunity to discuss Mr. Moore's paper. The following discussion took place at the General Meeting May 20th, 1896.]

Mr. C. P. Steinmetz:—Mr. President and Gentlemen. While reading, and afterwards listening to the presentation of the paper on "Recent Developments of Vacuum Tube Lighting," a number of points occurred to me with which I cannot agree. The foremost criticism which I have to make against the paper as a whole, is the same as that which I had to make only recently against another paper, namely, that it contains a number of vague claims and statements, without offering any proof for them.

Coming now to an analysis of the paper, I find on the second page a statement with which I must beg to disagree, namely, that the paper "represents radical departures in principle, in apparatus, and in the nature of the current."

The electrostatic discharge is produced by a sudden change in the electric circuit, consisting of a make and break of the circuit.

This is precisely the same method used since the early days of the Ruhmkorff coil, with the only exception that the interrupter is placed in a vacuum. The absence of a secondary coil is not new, but not desirable where the primary E. M. F. is very low, as a battery cell, as stated on page 97.

The allusion to the ponderous alternator, oil transformers, magnetic blasts, the millions of volts required, etc., is obviously gross exaggeration.

One disadvantage of this vacuum interrupter, compared with the condenser discharge across a spark-gap, has been already noticed by the lecturer. While the condenser discharge through the spark-gap makes its own frequency, with the vacuum interrupter the circuit has to be carefully adjusted to some condition of resonance. That the nature of the current produced by the vacuum interrupter does not differ in any way from that of any electrostatic discharge,—either oscillatory or steady, according to the circuit conditions,—is self-evident. The phenomena produced by this electrostatic discharge in vacuum tubes, and described in the paper, as the luminescence of the conductor and of the electrostatic field of force, the diffused glow at a different degree of vacuum, etc., have been observed many times before, and exhibited with nearly the same brilliancy, for instance, at the World's Fair in Chicago by Mr. Tesla. The use of external electrodes in vacuum tubes is old.

The luminescence of the interior of the spiral in no way contradicts Faraday's experiment, since the interior of an open spiral is obviously not the interior of a charged body, and Faraday's experiment, as is well known, refers only to electrostatic charges at rest, but not in motion.

What cause the lecturer has to claim an irregular period for the oscillations produced by the condenser discharge through an inductive circuit, I cannot see, since it was with such discharges that interference and nodal points of electro-magnetic waves have been observed. The wave length of an electric oscillation is not shorter if the wave is quicker, as stated by the lecturer. It is well known that the period of oscillation is entirely independent of the rapidity of the break, and only the amplitude can be affected thereby. Thus the conclusions drawn herefrom are erroneous.

The calculations on page 100, on the counter E. M. F. of the ether gap and its particular and radically novel features, are too fantastic to pass any scientific scrutiny.

A number of other statements in the paper are unintelligible, as, "natural period of a coil," or "governing the period of oscillation"—by the way, through the high resistance of the vacuum tube, the discharge is probably not oscillatory at all, but steady—or "compensating for the long wave length by a discharge coil," or the action of return wire, etc. Other remarks border on mysticism as, "striking nature's key-board to the tune of 500 trillions of waves per second," etc. In general it is to be

regretted that a large part of the paper is written in a style more befitting a sensational newspaper than a scientific or even technical society.

After criticising what the paper says, I may add a few words regarding what it does not give, but what such a paper, to be suited to such a body as the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, should give.

At the risk of being included by the lecturer amongst those lacking in information, I must nevertheless raise the all important question, "How many watts per candle power do you require"?

I cannot see any difficulty in determining this. Compare the light given in one metre distance by one of these tubes, with that of a standard candle, in the Bunsen photometer. The total candle power of the tube, to that of, say, an incandescent lamp, will be proportional to the area of the surface at one metre distance from the tube, to the area of a sphere of such a distance from the standard candle or lamp, as to give the same illumination of say 1 cm.^{2} of a white surface. Or if you object to the difference of color, compare by means of colored screens the intensities, say at the points A, D and F of the spectrum.

Or taking a more concrete case: The lecture room was illuminated by 27 Geissler tubes of about 7 feet length and 2 inches diameter, instead of 22 incandescent lamps as usually. Compare the intensity of the light reflected by 1 cm.^{2}, white surface in either case, with a standard candle in the Bunsen photometer. This will give you an exact measure of equivalence. I should judge the Geissler tube light to be about equivalent to five or six 16 candle-power lamps. Now determine the amount of power taken from the supply dynamo. I saw a 7½ H. P. Crocker-Wheeler motor driving the dynamo, and from the hum of the motor it seemed to slow down noticeably if the load was thrown on the dynamo, and a 7½ H. P. Crocker-Wheeler 500-volt machine flashed badly, showing either a defect in the machine or an overload. This does not look like high efficiency. However, a public demonstratration is not very suitable for such tests, but they should have been made before in the laboratory, and their results communicated to us here. Thus, while the paper is very interesting as showing improvements in Geissler tubes, or illumination by Geissler tubes, no data whatever are brought forward regarding the only and all important question: "How does the power required for lighting with Geissler tubes compare with that required for the same illumination by incandescent lamps?" I may add in closing that the paper would have been essentially improved if all reference to Galileo about the interference of the inertia of the learned with the progress of science, etc., had been omitted.

THE PRESIDENT:—There is a communication on this subject by Mr. J. P. Wintringham, which will be read.

MR. J. P. WINTERINGHAM:—This paper seems to have some interesting new matter, but the author has written a little carelessly, and I would note two or three lapses. He speaks of the counter E. M. F. of the air-gap. The effect is not a counter, but a direct E. M. F., and is due to self-induction, not to the air-gap.

He speaks of a high frequency oscillating discharge, which term has a special technical meaning among electricians, referring to the discharge of a leyden jar, etc.

He seems to deal with a branched circuit, the current of one branch being periodically interrupted, the current in the other branch being also periodic. There does not appear to be any charge and discharge or any oscillation involved.

What I have said applies to the lamps with two electrodes. Some of the lamps had only one, and the tubes were without any electrodes. Here there would be condenser action, charge and discharge. The question if it is oscillating would be determined by a formula put as follows by a very high authority:

The resistance must be less than $2A\sqrt{\frac{L}{C}}$ for the discharge to be oscillatory. A = the velocity of light, 30 earth quadrants per second, or, say, in practical units, 30 ohms. As L, C and the resistance are not given, it can only be conjectured that the discharge may be oscillatory.

The time of an oscillation would be given by the formula

$$T = \frac{\pi}{A}\sqrt{L\,C}.$$

As A has a value 3×10^{10}, any ordinary value of $\pi\sqrt{L\,C}$ would leave T so small, and the number of oscillations per second so large that the number of makes and breaks of the contact maker would be of a different order of magnitude and entirely incommensurable with any high frequency effect.

So the expression, "when the rate of the vibrator is the same as the natural period of the coil or any of its harmonics" would seem to be meaningless.

DR. E. L. NICHOLS:—I was not fortunate enough to read this paper. As regards the probable efficiency of vacuum tube lighting, I may say however that we are not absolutely ignorant with regard to the efficiency of the Geissler tube discharge. Measurements were made in Zurich by Dr. Staub on the tube itself, in which he got the radiant efficiency, which ran very high, sometimes as high as 33 per cent. That means that the spectrum of this source is very largely luminous in its character. A few years later Prof. Angström made other measurements with the Geissler tube, in which he included the losses in the generator circuit. The heat lost in a generator circuit of such tube being from the very nature of the case large; where you use an interrupted circuit you may expect that. He found as a result of bolometric measurements that while the radiant efficiency some-

times reached 90 per cent., that only about eight per cent. of the energy expended in running such a tube was converted into light. This would seem to indicate that vacuum tube radiation, if produced by the means at present known to us, or, at least, by the means used by Prof. Angström, is not likely to be found, of extremely high efficiency. In order to secure a vacuum tube discharge which shall be of very much higher efficiency than other electric lights, you have got to devise some means of generating that discharge which shall be free from the losses which exist with any ordinary make and break apparatus.

Mr. Steinmetz:—About a year and a half ago I experimented somewhat in the same direction, and tried to measure the power consumed by Geissler tubes. While these tests have never been completed, due to more urgent work, I noticed that the efficiency of the Geissler tubes apparently depends to a large extent upon the frequency. With very high frequency, as by oscillating currents, the vacuum tube gave quite a noticeable amount of light while remaining perfectly cool. With a frequency of ordinary machine currents, however, when giving about the same amount of light, the tubes became noticeably warm.

Mr. L. M. Pinolet:—In the absence of Mr. Moore, who is detained by sickness, I wish to explain that the slowing down of the motor, which has been referred to, was not caused by an overload but was due to the fact that the motor was run with the resistance of the starting box only partly cut out. Measurements made the night following the lecture showed that the magnets with their vibrators took about one eighth of an ampere each at a pressure of from 450 to 500 volts. Since then a change has been made in the apparatus which has reduced the current consumption to about one tenth of an ampere. In making these measurements, it was noticed that the brightest tubes took the least current.

Prof. Anthony:—I would like to know exactly where the ammeter was placed when these measurements were made?

Mr. Pinolet:—It was placed in series with the vibrator and its magnet; whose current was to be measured.

Mr. N. W. Perry:—The statement that he was present when the test was made showing a consumption of energy in those 27 tubes being exceedingly small is interesting. I saw a gentleman present here a little while ago who I think could tell us just what the results were that were obtained and how the tests were made.

Mr. Wolcott:—Mr. Moore told me last night that he took about forty watts per tube.

The President:—Do you know how many tubes there were at the Institute meeting.

Mr. Pinolet:—Twenty-seven.

Mr. Wolcott:—In justice to Mr. Moore I will say that he has since succeeded in getting a much better quality of light than that exhibited before the Institute.

Mr. Carl Hering:—In connection with this light the question is often asked, how many candles are generated per watt. It seems to me that it is not quite right to put the question in that form, if it is intended to make a comparison with other forms of electric lighting. I agree with Mr. Moore in his statement that it is not altogether a question of watts per candle; the real question is, how much energy does it take to light up a given room with this and with the other systems, so that the effect is the same to the human eye. Except for photography, we generate light so as to be able to see, and therefore if the effect on the eye is the same, it does not make any difference to us how many candles of light there are generated in that room. It is well known that if a certain amount of flux of light is all concentrated in one small point, it becomes glaring and dazzling, and the retina of the eye contracts, thereby limiting the amount of light admitted into the eye, while if that same amount of light were distributed equally, as for instance when reflected from white walls or emitted from the surface of large Geissler tubes, it would have a much better effect on the eye and would produce what would be called a much better illumination. I therefore do not think too much stress ought to be put on merely the number of candles produced per watt in this system, without also considering the very important factor of the distribution.

Mr. A. E. Kennelly:—Mr. President: It has given me great pleasure to witness the distinct advance that Mr. Moore has made over the Geissler tube in the production of light by high tension discharges. This is a direction in which advance may be looked for, and in which we may hope that success will ultimately be achieved. Yet I think we should face the facts as they are, if only for the sake of having an accurate criterion as to how far progress is made, and I think we should face the question as to how much light is produced for a given quantity of power. Of the forty watts which are said to be supplied to one of Mr. Moore's tubes at the present time, we cannot believe that all are expended in light. It would seem probable that most of it would be expended in exciting the magnet whose discharge produces the light, in the same way that a fifty-candle power lamp absorbs fifty watts to produce a relatively small activity in visible light. The fact that the tube occupies an extended space and offers an extended surface, does not really come into the question. What we want to know is, how may units of light are produced from this tube, considered as a source of light, for the alleged forty watts which are supplied to it. That is a perfectly definite question capable of a perfectly definite answer, and if that answer can be given to us at the present time it will at least afford us a valuable criterion of the advance which Mr. Moore has made in the art of Geissler tube lighting.

Mr. E. E. Ries:—I coincide perfectly with what Mr. Hering and Mr. Kennelly have said in discussing this new method of Mr.

Moore's, that it is not proper to compare it with existing standards of candle-power; that is to say, with systems of concentrated lighting to which we have been heretofore accustomed. The new system operates by diffused light; that is, a lesser intensity of light, given forth by a larger emitting area. Now, if it can be shown that the luminosity given by this method to an apartment or room is sufficient for practical purposes, that is, for the purposes of reading or working by, at a fairly economical cost, it will denote that a considerable advance has been made. I do not think it wise for the members of the INSTITUTE to condemn a new invention at the outset, simply because it has not arrived at that stage of efficiency which, if the theoretical principles underlying it are true and correct, it will probably eventually attain. All methods of artificial lighting are more or less inefficient. We have to spend a great deal of electrical energy in producing waste, either in the form of heat or chemical action, or both, in order to get some light. In the incandescent electric lamp a large waste of energy occurs, and in other sources of illumination similar wastes takes place. It is possible that in the vacuum tube system the waste incidental to the excitation of the magnet, and the other losses due to the resistance of the air-gap, etc., which appear to be the seat of the principal losses in this case, may eventually be minimized. I think it well to defer giving a hasty decision until that point can be determined.

If I recollect rightly, some years ago I saw a statement to the effect that Mr. Moore had been experimenting on a make-and-break in a vacuum containing a vibrator very similar to this, for the purpose of producing a regulating socket or controlling device for incandescent lighting by intermitting or interrupting the flow of current passing through the lamp filament more or less frequently. The method itself was not new, but the means of accomplishing it—that is, the making and breaking of the circuit in vacuum—was new. I am very glad to know that from that initial starting point this later achievement in tube lighting has been evolved. It is another one of those curious instances where an inventor originally starting out on one line of investigation discovers, turns up and develops something in an entirely different direction. I hope that future developments in this respect will show that something valuable may be expected from this new method of lighting.

MR. STEINMETZ:—I must protest, Mr. President, against the imputation that anyone wants to condemn this paper. What we want is to get exact data and not mere general statements. What we condemned was the entire absence of numerical data in the paper.

MR. CARL HERING:—We know the arc light is much more efficient in candles per watt than the incandescent light, yet we use the incandescent light, because we can distribute it. It is possible that even if in the light under discussion the amount of

energy required per candle power is greater than in the incandescent light, it might nevertheless be a more economical way of illuminating a room.

MR. PERRY:—That brings up another point. I think all of us who saw that exhibition were guessing as to how many incandescent lamps distributed judiciously through the hall would enable a person to read with equal ease. All the guesses that I heard gave a very small number. Mr. Hering's point was that the larger surface ought to give us better results. That is so, and measuring by incandescent lamps would not be unfair to the lamps and favorable for the tube. The only data we have as to the power consumed in those tubes was the behavior of the generating apparatus. There are a great many who saw those instruments work. I could see the motor part of the time, and the rest of the time I could hear it, and my impression was that there was not less than ten horse power generated. If we hear a 7½ H. P. motor laboring as that one was, it is a pretty sure indication that energy is being generated, and this must have gone somewhere. If we divide it up among those 27 tubes and it gives no more diffused light than a comparatively few 16 candle power incandescent lamps then it would seem to indicate that the light was a very expensive light.

MR. KENNELLY:—While I agree in some respects with the last speaker, I think that matter ought to be viewed from a somewhat different standpoint. We have here a new means of electric lighting. I do not suppose that anybody thinks that means has advanced to a practical stage. That is not the question at present. The question is, what is the possibility of this means becoming better in the future? In that point of view it becomes of interest to know just how the facts stand. These tubes produce light, and the light is capable of being measured. They absorb power that is capable of being measured. In the INSTITUTE the other night, by an arrangement of white screens behind the tubes and gauze above them, an illuminating effect was produced in the hall. But we want to know how much light these tubes produce for a given quantity of energy. We shall then have something by which to judge of future progress.

PROF. WILLIAM A. ANTHONY:—The candle power is simply a measure of the flux of light, whether it comes from a small point or a large one. If we hang up the arc light, what we observe is the illumination upon a little screen within the photometer carriage, and we make that illumination equal to that of the standard. There is no change in the size of the retina here. The brilliancy of the arc lamp does not directly affect the eye. But we compare its illumination on a screen, with the illumination of another source of light and so measure the intensity. The fact that we cannot use the arc lamp itself with the same efficiency in illuminating a given space that we can a smaller source of light, has no bearing upon this

point that I see. In the case of illumination by means of these tubes, the tubes present a large surface. It may present advantages as regards the distribution, but that makes no difference with the amount of candle power per watt. In regard to the results the other night at the INSTITUTE meeting, I took pains while the tubes were being used to observe how well I could see to read, and tried to compare that as well as I could with the ease with which I could read by means of the incandescent lamp. When the 27 tubes were in use it was certainly very much more difficult to read than when the usual lamps were employed for lighting the hall. I think that was evident to everybody. How much more difficult it was, I could not say. When the one large tube in the front of the hall was doing its very best, the one large tube with a reflector behind it, I could see to read nearly as well as when the reading lamp that was used on the desk was turned around, as it sometimes was, towards the hall. I was not able to see as well by the one large tube as I was by that single reading lamp. That, it seems to me, is a fair comparison of the illuminating power of those two sources, and it is exactly what we want to know about. The absence of such information is what we are criticising in Mr, Moore's paper. Mr. Moore has certainly done a great deal, and has made a great advance in vacuum tube lighting. He has accomplished something that we have never seen done before. But at the same time we would like to know just how much light he will give us per unit of energy expended.

DR. NICHOLS:—If the photometer is not for the purpose of measuring the illuminating power of light what is it good for? The work of the committee on light standards would seem to be wasted if when we got through we are not going to be able to measure the power of all sorts of light. The light which falls upon the disk of the photometer produces there an effect which is entirely independent of the area of the source. It does not make any difference to the man who is looking at the photometer whether the source is concentrated or not. If you test your light by some other criterion, the question of diffusion may come in. If you are standing with your back to an arc light you cannot read in the shadow. There is a certain benefit which is obtained by distributing your light so as to avoid showy shadows. All other benefits than that of getting rid of black shadows is entirely fictitious, unless the bad effect upon the retina of gazing at intense sources of light be considered.

MR. RIES:—It does not seem to me to be a question of relative candle power so much as the amount of energy required to produce the required light, or, more properly speaking, the utility of the light in comparison with its cost. When it comes to a question of measuring light by candle power that is one thing, but so far as its *commercial* use is concerned that is quite a different thing. If we take an arc light, which will give us 2,000 candle power

with an expenditure of one horse power of mechanical energy, we will, by expending the same amount of energy, be able to get at the most about 200 candle power out of a number of incandescent lamps, yet because the latter are only one-tenth as efficient as the arc lamp, that is no reason why we should dispense with incandescent lamps, nor do we dispense with them upon that account. In the case just cited we sacrifice a good deal in efficiency for the sake of subdivision and better distribution of the light, and it seems to me the vacuum tube method holds forth the promise of a still further refinement in this direction and in all probability at a far less sacrifice of economy. If vacuum tube lighting can be brought in the future into commercial use for the lighting of the interior of rooms it will have a field peculiarly its own. It will not drive out the electric arc light or the incandescent light, but it will open up a new field for ornamental and decorative lighting effects where intense luminosity is not required, and it is perfectly conceivable that with a satisfactory means of vacuum tube lighting, which of course is not concentrated like that of the arc and incandescent light but is capable of a more uniform, and for many purposes a more desirable diffusion, a great many practical uses may be found for it. From that point of view I say that it is not so much a question at the outset to criticise Mr. Moore's new method, or his improvement in the Geissler tube method, simply because at present, from our lack of information, we have not the data which shows us exactly what it will cost. If the cost is reasonable—even if it should be greater than the cost of incandescent lighting—it may still have a future before it. It seems to me that the question now is, to discuss the matter from the standpoint of an improvement in lighting rather than to criticise it at the outset too strongly from the point of view of its economical advantage over other forms of light.

MR. WOLCOTT:—One reason why the members have all taken the stand of the efficiency of this light is that the paper spoke of the incandescent light as very wasteful. The idea was that this was a cold light which took very little energy.

MR. KENNELLY:—I do not desire to criticise Mr. Moore's work in this direction, but we want to know just how much to admire it. If we have from Mr. Moore a statement of how many candle power he can produce, why, we obtain a criterion by which we can measure his success.

MR. HOWELL:—I do not think Mr. Moore would have the slightest objection to telling us all he knows about this. I do not think he would have any objection to answering every question that has been asked here today about it. There is one thing that was brought out by Mr. Moore that night which has not been touched upon, and that is the difference in color between the vacuum tube light and the incandescent light. You will remember that he held up a tube in a reflector, and alongside of it his

reading light, to illustrate the difference in color, stating it was his belief that the color of the tube light was very much superior to that of the incandescent light. It was my impression that the color was a very poor one, and that the whiteness, or greenness as I called it, of the light, was a very great disadvantage to it. I think the disadvantage of that whitish light has been shown by Dr. Birchmore in a series of articles in *The Electrical Engineer* in which he shows the action of different colored lights upon the retina of the eye, showing that the rays from the violet end of the spectrum rather contracted the pupil very much more than rays of light from the lower end of the spectrum. The contrast which he made between his light and the other was a strong argument in my mind against it.

THE PRESIDENT:—Mr. Moore has just come in. We should like to hear from him.

MR. D. MCFARLAN MOORE:—Mr. President and Gentlemen: Owing to a bad cold it will be difficult for me to make myself heard. The ideal light will undoubtedly only be reached when we can produce by artificial means a light which is the same as daylight. Since my method of vacuum tube lighting was exhibited at the last INSTITUTE meeting, improvements have been made in it so that I can produce at this moment tubes with a daylight spectrum. The vacuum tube method is the only one which presents itself for our use, in order to produce a light which will be anywhere near a counterpart of daylight,—a light which will be radiated from long tubes. In relation to efficiency, of course it was understood that the paper was presented merely to call attention to the advance that has been made. In order to appreciate that advance, a person must understand how very inefficient previous experiments and methods have been. The vacuum vibrator is undoubtedly a device which has greatly improved the economy of tube lighting over previous systems. Previous methods used a break in an electric circuit in the open air in order to produce the secondary current which would have certain properties necessary to produce the agitation in the tube and cause the light. In all those systems the break came into the system somewhere. Anybody who has experimented with a break in the open air, knows that it is very remarkable how much energy can be wasted. An enormous amount of power is dissipated in the open air break. Now, when that arc is placed in a vacuum which remains perfectly cool, it is apparent without any further discussion that there results an enormous saving. During the test at the INSTITUTE which has been referred to, the apparatus was run without the slightest difficulty and without anything getting out of order. A number of tests were made by the parties who were present, as to the range of legibility. That was the only way by which we could get any idea of the consumption of power necessary to produce a quantity of "cold" light, the equivalent of which could be gauged by incandescent

light. It was undoubtedly a fact that objects on the wall of the INSTITUTE could be discerned a great deal better with the tube lighting than they could with the 25 incandescent lamps. As to the power consumed, there was at no time more than two amperes used. Now, that is the only basis we have to calculate from, as far as power is concerned, viz., that you could distinguish objects better with two amperes, which is of course a less amount of power than required by 25 incandescent lamps. Since then I have well nigh cut the power required in half, and also increased the quality of the light. In fact, it is difficult to say just what power would be required to produce the same amount of light with the break in the open air; but if the same amount of light were to be produced with the break in the open air and by the inductive method alone, I am not exaggerating to say that the increase of efficiency is about eleven million per cent. This sounds outlandish, but it is a fact.

I do not know that there is anything more for me to say, except that I will take great pleasure in explaining my apparatus to anyone who wishes to examine it. I can add that the spectrum from my tubes is absolutely continuous, something never obtained before from vacuum tubes.

MR. WOLCOTT:—I would like to ask Mr. Moore one question. On page 88 of his paper he says: "As a device for transforming electrical energy into light, the vacuum tube is very efficient. The majority of authorities place it at about 70 per cent. and the incandescent lamp at two per cent." I would like to know what is the basis for that. Does he mean 70 per cent. of the energy which is supplied to the electrodes appear as luminous radiation?

MR. MOORE:—Yes, undoubtedly. I wish also to add that the idea in showing the difference between the incandescent light and the vacuum tube light was merely to show that the vacuum tube light had very few red and wasteful heat waves. With reference to efficiency of course it is understood that I referred to the amount of power consumed at the terminals of the lamp, and that this system of lighting, without heat, is merely a step in advance. We must come to it, and rapidly, and it is merely a step in that direction. The heat is not all removed but we are approaching that end.

MR. WOLCOTT:—I have never heard that a Geissler tube had 70 per cent. efficiency.

MR. MOORE:—I think Dr. Nichols can give you some points on that subject.

DR. NICHOLS:—The figures referred to are doubtless those to which I referred a few moments ago. Dr. Staub had a Geissler tube in an ice calorimeter, so that he was enabled to allow the luminous rays to escape. Then he blackened the walls of the tube and absorbed it all, and he found in that way about thirty-three per cent. efficiency. On the other hand, in the second set of

observations—those of Prof. Angström—comparisons were made between the luminous radiation, produced in a Geissler tube, and the total amount of energy electrically measured necessary to generate that light in the tube, the efficiency in such tubes thus tested was about eight per cent. This second quantity, which would seem to limit the total efficiency of the Geissler discharge at less than ten per cent. is a question of course of the method of generation, and if you can reduce the loss in the outside circuit then the luminous efficiency may be greatly increased.

Mr. Wolcott:—Even at ten per cent?

Dr. Nichols:—You have to divide that by the fraction of light-giving energy in it.

Prof. Anthony:—It seems to me that a good place to put a voltmeter and an ammeter is in the circuit that drives the motor. If we put the voltmeter and ammeter in the circuit which drives the motor, then all question as to the measurement, by means of the ordinary instruments, of this extremely fluctuating current that goes into the tube, as to whether that gives us an accurate measurement or not, would be disposed of. We could tell then very nearly what amount of energy is required to operate the tube.

[At this point the President requested Vice-President Steinmetz to take the Chair.]

The Chairman:—I observe that Mr. Wetzler is present and some of the gentlemen have expressed a desire to hear him on this subject. Will Mr. Wetzler favor us?

Mr. Joseph Wetzler:—The tests made by myself on Mr. Moore's apparatus were carried out as follows: A Weston direct current milliammeter, A of the diagram, was placed in series with the inductance coil employed by Mr. Moore, and the potential was measured by a Weston alternating and direct current type voltmeter, V, connected directly across the leads. The results of one set of tests was as follows:—

	Volts.	Milli-amperes.	Watts.
Tube No. 1, good tube	490	110	53.9
" "	470	110	51.7
Tube No. 2, poor tube, faint light	480	160	76.8
" "	480	160	76.8
Tube No. 3, good tube	500	85	42.5
" "	485	110	53.3
" "	485	110	53.3
" "	485	110	53.3
" "	490	110	53.9
" "	490	110	53.9
Tube No. 4, good tube	490	108	52.9
" "	485	108	52.4
" "	470	108	50.7
" "	490	110	53.9
" "	470	105	49.3
Tube No. 5, good tube	500	*88	44.0
" "	500	*88	44.0

*With momentary rise to 120.

In other tests which I made I found some tubes that gave much lower watt readings than any of the above; thus one read as low as 30.5 watts. The above results may therefore be considered a very fair average. No special preparation, so far as I am aware, was made for these tests by Mr. Moore, and all were taken in his Exposition booth while the apparatus was being shown publicly.

MR. RIES:—I should like to ask Mr. Wetzler what was the length of that tube on which the 42.5 watts reading was taken?

MR. WETZLER:—All those tubes were about seven feet long. In fact they were the same tubes that were used at the INSTITUTE lecture. No measurements were made on the illuminating power of the tubes. They were all in good condition except the one which I have referred to as a bad tube, which was evidently lacking in brightness.

MR. RIES:—Then one of those seven-foot tubes took practically as much energy as an ordinary 16-candle power incandescent lamp?

MR. WETZLER:—Yes sir.

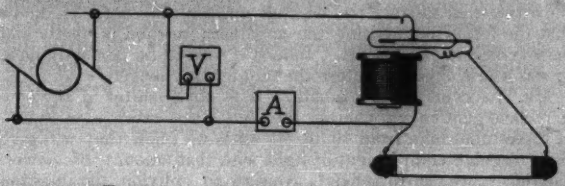

FIG. 1. ARRANGEMENT OF TESTING APPARATUS.

MR. MOORE:—I believe it was stated by somebody before I arrived, that the motor appeared to be overloaded. It is quite remarkable, when you consider all the motor experts there were at that meeting, that every one presumed that the motor was overloaded, and it only shows how unsafe it is to be too sure of anything. When the dynamo field rheostat arrived it was found when it was connected in circuit that you could turn its handle all the way on or off without affecting the voltage in the slightest degree. Therefore, it was a useless piece of apparatus, and it was not used. The motor starting box had seven points for varying its resistance. Now, at no time during the evening were more than three points cut in, in the motor starting box, and I think most of the time only two. Of course, anybody who is familiar with this kind of apparatus knows very well that when you have a motor with only two-sevenths of its starting box cut out when you put a slight load on it, it will lose its voltage. That was the whole truth of the matter. Of course if the attendant had turned the starting box all the way around and cut it all out then it would have been all right as it was the following night.

DR. S. S. WHEELER:—I attended the INSTITUTE meeting at which the new light was shown and I thought I noticed a

squeaking, indicating that the belt between the dynamo and the motor was slipping. I would like to ask Mr. Moore about that.

MR. MOORE:—Dr. Wheeler must have been mistaked. A number of men who are competent to know how tight a belt should be stretched, all agreed that the belt was all right. It worked perfectly, merely by throwing the resistance of the starting box out.

PROF. ANTHONY:—During one stage of the experiments I knew the motor starting box was not all cut out. That was when the first attempt was made to start up the tubes for lighting the hall. Later I saw the assistant go and turn it out, and I supposed it was fully turned out; I feel quite sure that it was. In regard to the laboring of the machine, it was not the laboring of a machine that was working with the starting box partly turned on, but it was the laboring of a machine that was overloaded.

MR. MOORE:—In response to that I must say that Prof. Anthony is entirely mistaken. I have the very best evidence to show that that starting box was not entirely cut out. I know that the following evening the apparatus worked perfectly and on several other occasions. Indeed it is working perfectly now, or was a few days ago before the motor was changed.

MR. KENNELLY:—Fortunately it is not a matter of any consequence, gentlemen, whether the motor was overloaded or not. If these tubes take from 40 to 60 watts we know they will give their regular complement of light with that amount of power. Therefore, we can fortunately consign to oblivion the question whether the motor was overloaded or not.

PROF. ANTHONY:—I don't feel so sure of that.

MR. WETZLER:—I would like to state that the measurements were made with two different types of instruments and on different days. One was a direct reading ammeter, and the other was an alternating and direct reading type of Weston instrument.

PROF. ANTHONY:—I am not certain that in that interrupted circuit any of those instruments will properly measure the energy consumed. The sort of current that is obtained by that interruption is something totally different from any alternating current, and it seems to me that it may very well be that the voltmeter and the ammeter would not measure truly.

MR. PERRY:—I have felt the same way that Prof. Anthony has, that neither the direct nor the alternating current measuring instruments would be likely to give us results which would not be open to some question. There is another question that I would like to ask Mr. Wetzler. I think he stated somewhere that the total number of tubes consumed a given total amount of energy. I think I saw that in some editorial of his.

MR. WETZLER:—I do not recall the exact language.

MR. PERRY:—I understood these tubes were each on a separate circuit. Now, were the tests of all the tubes made on instruments simultaneously or under what conditions?

MR. WETZLER:—While all the tubes were operating I tested one of them at a time. Each tube being on a circuit of its own I would naturally measure one at a time.

MR. HERING:—Perhaps a voltameter might be a much better instrument for such currents than an ammeter; if so, a simple Edison meter might answer the purpose.

MR. MOORE:—Mr. Wetzler has told you that he measured but one vibrator at a time. I measured a number all at the same time, and found the current consumption proportionately the same. With reference to Prof. Anthony, he seems to be determined that that motor was overloaded. I may be able to help him out in that matter. As is well known, when a motor under those conditions has a load placed upon it of course it will drop in its speed. Then the dynamo may drop from 450 down to less than 100 volts and of course the vibrators would stop vibrating, and the moment they do that, there is a short circuit through the coil and immediately the amperage would run up enormously. So that may well explain why the motor appeared to be overloaded. The fact of the matter is, however, that it never was overloaded. I wish to state once more that this matter of efficiency is absolutely secondary. I was able to light up a hall, the first hall in the world to be so lighted. I have placed my work before you claiming an advance in the art, irrespective of the question of efficiency, although I have nothing to be ashamed of in that direction, in fact the opposite.

[COMMUNICATED AFTER ADJOURNMENT BY PROF. ANTHONY.]

The doubt which I expressed in the discussion at the meeting in regard to the truth of the indications of the Weston instrument when used to measure interrupted circuits was set at rest by experiments I was able to make on Wednesday evening after the meeting of the INSTITUTE, and of which I gave an account in a report to Mr. Moore which is printed in full below.

NEW YORK, May 27, 1896.

D. MCFARLAN MOORE,

DEAR SIR:—On Wednesday evening, May 20th, in company with Prof. E. L. Nichols and Mr. Nelson W. Perry, I made a test of the power absorbed by the vacuum tube light in your exhibit at the Electrical Exposition, with results as given below:

A Weston ammeter was placed in the circuit leading to the motor used for driving the generator which furnished the current for the vacuum tubes, and a Weston voltmeter was placed across the motor terminals. These instruments were read at frequent intervals, while one of us in the booth below noted the time of turning on and off the light. Comparing notes, we found that when the tubes were all off, the motor consumed 12.5 to 13 amperes at 110 volts as a constant load. When the tubes were all on, the motor consumed 23 amperes at 108.5 volts.

The motor therefore comsumed, when tubes were not running ..1400 watts.
When tubes were all running .....2380 "
Due to tubes..... 980 "

There were in operation 14 tubes, 7½ feet long, 1¼ inches diameter, 1 tube somewhat shorter but 2½ inches diameter, and a few tubes of special designs.

We estimated that the whole was an equivalent of 16 of the 1¼ inch tubes. This gives 61 watts per tube applied to the motor terminals. Assuming that 80 per cent. of this energy was delivered to the tubes from the generator terminals, the power consumed by each tube is 49 watts.

This is practically the result obtained by Mr. Wetzler by direct measurement of the energy consumed by the tubes, and disposes of the question raised by the writer as to the reliance to be placed upon the indications of a Weston ammeter in circuit with a vibrating interrupter.

The only question now is, as to the intensity of the light obtained. Of this it was impossible under the conditions to make any reliable estimate. Our results simply show that the light of the vacuum tubes, as exhibited in your booth at the exposition, is obtained at an expense of a little more than one horse power.

The instruments used in making these measurements were kindly loaned for the purpose by Mr. Pionnie in charge of the Weston Electrical Instrument Co.'s exhibit, who gave us his assistance in making the necessary connections and in taking readings.

W. A. ANTHONY.

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Contents of Vol. XIII. 1896, as far as Published.

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Vol.
189